

**Title****Preliminary Design of On-Orbit Manufacturing of Large Antenna  
Reflectors****Executive Summary Report**

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## GLOSSARY

APM	Antenna Pointing Mechanism
ESA	European Space Agency
CDF	Concurrent Design Facility
CONOPS	Concept of Operations
CS	Clean Space
FDIR	Failure Detection Isolation and Recovery
CFRTP	Carbon Fibres Reinforced ThermoPlastic
GEO	Geostationary Orbit
I/F	Interface
ISMA	In-Situ Manufacturing and Assembly
LEO	Low Earth Orbit
OMAR	On-orbit Manufacture, Assembly & Recycle
OOMA	On-orbit Manufacturing and Assembly
OSS	O-orbit Servicing Station
P/F	Platform
P/L	Payload
ROM	Rough Order of Magnitude
S/C	Spacecraft
TRL	Technology Readiness Level

## 1 INTRODUCTION

Through its Clean Space (CS) initiative, ESA has been devoting an increasing amount of attention to the environmental impact of its activities, including its own operations as well as operations performed by European industry in the frame of ESA programmes. In ESA's Technology Strategy, the Agency has identified as one of the four technology development targets Inverting Europe's contribution to space debris by 2030. The current activity is intended to support achieving the target.

On-orbit manufacturing and recycling is a concept that has been gaining momentum in the past years. A number of isolated technology developments have taken place recently. The reuse of space debris in orbit would turn a problem into a valuable asset.

However, before recycling a satellite, or manufacturing satellite parts in orbit, the understanding of the implications at system level is crucial as well as a clear view of the use cases that could benefit from this approach. Furthermore, a new AIT approach would have to be defined to fully benefit from the removal of constraints linked to on-ground manufacturing and launcher requirements. To address this complex issue, a comprehensive systems approach involving a multidisciplinary team and exploring synergies among the different possible scenarios and building blocks is necessary.

With this aim, ESA has set up the OMAR (On-orbit Manufacture, Assembly & Recycle) initiative. OMAR is a system approach aiming to give an overview of the most interesting applications, map the state-of-the-art and derive a roadmap for the development of the critical technologies. The proposed approach follows 3 steps:

- Step 1 – Preparatory small CDF study: screening the relevant mission scenarios, assess feasibility and derive systems architecture This activity is completed.
- Step 2 – Industrial studies: addressing main system segments based on established architectures (i.e. paradigm change on satellites design, on-orbit manufacturing/recycling plant, and logistics segment including servicing vehicles).
- Step 3 – Full CDF study: Preliminary system and subsystem design of all elements based on industrial inputs, consolidation of the mission scenario and concept of operations, definition of system interfaces between the different segments, evaluation of industrial and economic impacts of the proposed approach, definition of technology development roadmap.

In the frame of Step 2, four industrial activities will be carried out in parallel. These studies aim at understanding the possible strategies, system level impacts and potential benefits, while exploring the trade-space.

The On-orbit Manufactured Large Antenna Reflector Preliminary Design study is part of this Step 2, alongside On-orbit Servicing Satellite design study, Mission Architectures and On-orbit Manufactured Spacecraft.

**1.1 APPLICABLE DOCUMENTS**

[AD-1] TN1 State of the Art and Use Case Definition (Ref: RD-TN-ADST-1000755256)

[AD-2] TN2 Preliminary Design Requirements – issue 3 (Ref: RD-SP-ADST-1000755258-issue3)

[AD-3] Preliminary Conceptual Design, Processes and Materials (Ref: RD-TN-ADST-1000809936)

[AD-4] TN3 Conceptual Design of the Antenna Reflector Document (Ref: RD-TN-ADST-1000872515)

[AD-5] TN4: Technology Development Plan and Product Tree (Ref: RD-TN-ADST-1000914537)

**1.2 REFERENCE DOCUMENTS**

[RD-1] OMAR External Final Presentation (Ref: CDF-TN-073, Issue 1, 09/08/2019)

## 2 STATE OF THE ART, PRELIMINARY REQUIREMENTS AND USE CASES DEFINITION

The starting point is a state-of-the-art looking at antenna designs focused on assessing the currently used technologies against the specific requirements for on-orbit manufacturing.

Despite the enormous range of design variation for an antenna reflector, there are some key features of the key components of the antenna which are consistently the design drivers. These key design drivers result in a relatively limited selection of technologies and materials which have been found to be the most useful for a large range of different antenna designs.

For the purposes of this study it is proposed that since the critical driving requirements for many of these applications are the same, it is not necessary to select a very specific application use case.

For at least one of the use cases, we suggest that the study should adopt certain requirements which are deliberately 'worst case' since by doing so, the less stringent requirements deriving from less demanding use cases will be automatically covered by comparison. This approach also allows for a fall-back position in a situation where it proves impossible or too difficult to meet those worst case requirements, that the developed solution will still have applicability to as large a share of the potential market as possible. Requirements which fall into this category would include:

- Surface accuracy (as-built, thermo-elastic, dynamic)
- Pointing stability

Requirements that would be common for less stringent use cases are:

- Mass: as low as possible consistent with achieving all other requirements
- Stiffness (considered 'fixed' at spacecraft interface): 1st mode >0.5Hz.

The logic which has been applied in selecting the 2 cases listed below is:

- To look for likely cases which are realistic options to be '1st application' or 'break-through' opportunities for the on-orbit manufacture/assembly technologies in the reasonably short term. i.e. sufficiently close to existing mission definitions to be well understood in terms of the proposed application
- To look for cases which make sense in terms of driving the early development of on-orbit manufacturing technology. i.e. cases which use the range of fundamental capabilities which should have a wide range of application to other domains/products. And not to choose a very complex highly specific application which requires specialist capabilities with little prospect of further application.
- To choose 2 different cases which drive the technology towards different goals

It is considered outside the scope of this study to try to justify the business case for any proposed application, since these depend on many factors beyond our control. These cases are proposed as the best ones to drive the design studies in the subsequent work packages, to best understand applicability to the widest range of applications.

As a result, the two use cases that have been selected for the following steps of the study are:

- **Use Case 1: Focus on a 20m diameter high frequency (Ka Band) off-set parabolic reflector.** Operating in GEO, and supported multi-beam feed systems, this concept could have applications in providing high data transfer capacity between small regions of high population density. This concept is chosen because it drives many of the critical requirements to the extremes, and therefore will expose the key difficulties, and possibly identifies the limits, in solving the engineering problems associated with building such passive structures on orbit.
- **Use Case 2: 30m diameter off-set parabolic reflector operating in lower frequency (S band).** Operating in LEO, this use case is suggested because it covers some of the likely use cases at the other end of the spectrum. It is applicable to Earth Observation (SAR - Synthetic Aperture Radar) missions, but it could also be used for mobile communications services or IOT (Internet of Things) missions, where the data rate requirements are more compatible with the lower operating frequency.

### 3 PRELIMINARY CONCEPTUAL DESIGN, MATERIALS AND PROCESS PROPOSED COMBINATION

Many of the current on ground manufacturing processes and reflector designs are not compatible with an on-orbit manufacturing. This is why the design of the reflector will have to be relevant in term of OOMA capabilities.

For example, the on-orbit manufactured reflector could be made of:

- A variable proportion of parts manufactured-on orbit: the parts that form the reflector can either come fully finished from ground and only assembly is performed on-orbit. Parts could also be manufactured on-orbit with a dedicated process (ALM, forming ...).
- An average part size: large parts will limit the assembly/manufacturing time but leads to storage, waste management and possible inaccuracy issues. On the contrary, smaller parts will lead to a higher number of manufacturing and assembly steps but ease the storage, waste management and accuracy of the final reflector.

Different **conceptual designs** have been proposed with different manufacturing and assembly philosophy including parts size and proportions of manufacturing occurring on-orbit.

The conceptual have been ranked on the following criteria:

- Maturity/Risks
- Robotical Needs
- Mechanical Performance
- Radiofrequency Performance
- Versatility
- Pollution
- Lead Time
- Stowability

Similarly, a wide range of materials, manufacturing and joining processes have been studied and ranked according to relevant criteria such as:

- Mechanical Performance
- Resistance to space environment
- Cleanliness
- Reliability

Finally taking into account all the criteria identified, the combination of conceptual design, materials and process is the following:

- The **“Brick Reflector”** consists of the on-orbit assembly of on-ground manufactured blades and RF reflective surfaces to form a large reflector with 1m<sup>2</sup> pattern. The few and relatively simple

on-orbit operations made this performant design very promising for the two use cases defined in §2.

- **Long carbon fibres composite with a thermoplastic matrix (CFRTP)** seems to be the most relevant material to form the brick reflector. Indeed its mechanical performance and resistance to space environment makes it the ideal candidate to form the parts that will be assembled on-orbit.
- To assemble the CFRTP parts, bonding process is promising for on-orbit operations according to the criteria identified. **Dark cure epoxy films of thermoplastic fusion bonding films are the two baseline assembly processes.**

#### 4 PRELIMINARY REFLECTOR DESIGN

The on-orbit manufactured large reflectors of the two use cases are composed of hundreds of bricks attached together by their lateral flanges.

Each brick is composed of:

- A **frame** made of the assembly of 8 “L shaped blades”
- A **tile** which is a reflective RF surface will reflect the incoming RF wave and concentrate it at the focal point of the reflector
- **3 mechanisms** that allow to tune the orientation and position of the tile

Further than reflector conceptual design itself, the “Space Factory” that will perform on-orbit manufacturing, testing and integration steps of large antenna reflector has also been preliminary designed.

This “Space Factory” is composed of a robotic arm in the centre of the factory and different areas that correspond to different manufacturing steps. The main areas are:

- Robotic arm tool storage (6 different tools)
- Raw material storage area (blades, tiles and mechanisms)
- Frame Manufacturing workbench
- Brick manufacturing workbench
- Reflector assembly workbench

All the steps during the manufacturing of the large antenna reflector do not require very high accuracy on the robotic arm which relaxes a lot of constraints. The robotic needs are assumed to be basic (accuracy around 1mm and basic force/torque sensing for FDIR).

Preliminary mass, power and time budget have been estimates for the two use cases. The order of magnitude of mass for the reflector is 2kg/m<sup>2</sup> while the first estimate of manufacturing time ranges from 40 days (Use Case 1) to 90 days (Use Case 2). The overall power budget is quite low (600W) as only low power demanding processes have been chosen

## 5 TECHNOLOGY GAP AND DEVELOPMENT PLAN

The technology roadmap constitutes a reasonable plan for developing what is a very complex and challenging mission with multiple technologies never tried in orbit yet. Plus the whole definition of TRL has to be rethought by taking into account that some processes are directly happening on-orbit.

What emerges is a clear distinction between:

- On the one hand, on-orbit manufacturing technologies (materials, processes, operations) which are still in their infancy and considerable uncertainty surround their feasibility. In particular:
  - Bonding process happening on-orbit:
    - Dark cure epoxy have not been tested under vacuum environment, the curing under such conditions remains unknown.
    - Similarly, thermoplastic fusion bonding under vacuum has to be tested to validate its cleanliness.
  - Concerning the operations occurring on-orbit, some concerns might be raised about the reliability of such a manufacturing process that implies thousands of steps for the manufacturing of a large antenna reflector.
- On the other hand, the client satellite that will receive such a large appendix will require large evolutions based on existing technologies (AOCS, feed assembly, APM).

The high cost of the overall development reflects the standard approach to developing and qualifying space hardware used here, new space approach could be used to dramatically reduce the cost and make competitive products in terms of price and performance.

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